

Progress Report for NASA Grant NAG5-11100

Title: "Validating AIRS Ozone Observations"

Report to the EOS Program Office

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Executive Summary

The AIRS ozone validation team has made significant progress this year in validating the AIRS ozone product. Comparisons to ground-based observations and to TOMS global measurements suggests that AIRS total ozone column measurements are accurate to approximately $5\% \pm 5\%$, but with noticeable spatial variation with respect to TOMS and also some land/sea differences. Analysis of coincident ozonesonde profiles, both serendipitous and planned, is underway. Analysis of the channels used for ozone retrieval resulted in the suggestion of superior channels for ozone retrieval that will be incorporated in future revisions of the retrieval algorithm. Preliminary inspection of polar night ozone columns suggest that AIRS may be able to contribute useful scientific observations of the polar vortex ozone distribution prior to springtime sunlight and commencement of the ozone hole.

Research Objectives

We propose to assess the accuracy of the EOS/AQUA/AIRS ozone retrievals by comparison to accepted standards of measurements through a well-constructed, sequential approach. By close interaction with the AIRS algorithm team, we will quantify and minimize the precision and bias of the ozone measurements. Through interaction with the global modeling community, we will identify the areas of significant agreement and disagreement between our understanding and our measurements of atmospheric ozone.

In the first year, we will assess the total ozone column measurements with TOMS and Dobson measurements in the most benign atmospheric conditions. Then, with dedicated ozonesonde launches we will focus sharply on the accuracy of the ozone retrievals over more difficult conditions including partly cloudy scenes, day/night differences, and difficult viewing geometry.

In the second year, we will introduce additional standard correlative data (Umkehr, TOMS, SAGE, lidar) to assess the precision and accuracy of the tropospheric and stratospheric columns and extend the domain of comparison in both time and space. We will also focus on day/night differences using dedicated ozonesonde launches at Huntsville, AL.

In the third year, we will investigate the accuracy of AIRS to measure Stratospheric/Tropospheric exchange morphology and convective boundary layer diurnal differences. We will also place the AIRS measurements into the context of derived tropospheric ozone fields and of global 3-d chemical transport models to assess our understanding of tropospheric ozone morphology.

This comprehensive plan will result in a well quantified assessment of the AIRS ozone measurements in the troposphere and stratosphere over a wide variety of conditions, times, and places. We will also place these measurements into the context of regional and global ozone morphology.

Summary of progress and results

In the first year, we:

- Reported ozonesonde files in NetCDF format to the AIRS team and posted on the TLSCF.
- Compiled a list of 143 Brewer/Dobson/Ozonesonde/Umkehr stations around the world that have reported ozone data to the World Ozone and Ultraviolet Data Centre (WOUDC) since June 01, 2001, that we will use to validate AIRS ozone measurements. We are obtaining the data from the WOUDC and NOAA/CMDL as it becomes available.
- Established collaborative efforts with ozonesonde stations at Trinidad Head, CA, Boulder, CO, and Wallops Island, VA, to launch dedicated ozonesondes during AIRS overpass to quantify the continental gradient and verify the observed emerging climatology of [Newchurch *et al.*, 2002].
- Established collaborative efforts with Mauna Loa Observatory and Table Mountain Facility to obtain their ozone Lidar data [McDermid, 1993]. We are downloading the lidar data from NDSC as it becomes available.
- Launched 16 dedicated ozonesondes measuring the vertical profile of ozone, temperature and water vapor from Huntsville, AL as part of our AIRS validation efforts.

In the second year, we:

- With the availability of ARIS ozone data, we compared AIRS total ozone columns to Arosa Brewer, Boulder and MLO Dobsons in 2002.
- Flew 16 successful ozonesonde balloons from the Chesapeake Bay lighthouse with coincident BBAERI, UMBC ELF, and PGS RS-90 Radiosonde observations during AIRS overflights in June 2003 [Hinsta *et al.*, 2004]. Analyses of these profiles are underway.
- Focused on global ozone AIRS vs. TOMS global observations during January 2003.
- Investigated skin-temperature dependence of the retrieved ozone. Water-only, 40S – 40N.
- Investigated alternate AIRS channel selection for ozone retrievals from 9/6/2003 focus day. These superior channels will be incorporated in future retrievals.
- Investigated the potential for using AIRS in the polar night for total column ozone.
- Built a validation web site: <http://vortex.nsstc.uah.edu/atmchem/AIRS/>

Second Year Results

The volume of data returned from the AIRS instrument and processed by the Goddard Distributed Active Archive Center (DAAC) is enormous, on the order of 3.5 Gbytes per day. The amounts of data transmittal, archiving and computing resources at JPL are comparatively much smaller. Given these limited resources, on-line or archived data space for global retrievals is mostly limited to a select number of "focus days" and 31 contiguous days of data from January, 2003. It is for these days that testing of the AIRS retrieval algorithm against correlative mostly occurs. Also, daily Level 2 retrievals are calculated for a selected number of "matchup sites," for which vicarious validation data, mostly radiosondes but also some ozonesondes, may be available.

The AIRS retrieval algorithm has been extensively modified within JPL since launch, and is usually much more advanced than that used at the Goddard DAAC. For each internal update at JPL, only a limited amount of the level 1 data at JPL can be re-processed for validation purposes. The result is that archived data within JPL can be inconsistent with respect to retrieval scheme. As the retrieval of ozone from AIRS depends critically on the prior retrieval of humidity,

temperature and emissivity data, algorithmic changes that affect these parameters will also affect ozone results. This "version creep" complicates the statistics in comparing the limited number of co-located ozonesondes to AIRS ozone profiles. However, efforts to re-process all archived "matchups" using the same retrieval version are now being made. Also, as software updates are delivered to the DAAC, global re-processing of older data occurs. Thus, we expect within the next few months to begin to have a long-term, "constant version" AIRS data record which we can compare to in-situ measurements.

AIRS total ozone columns at Arosa Brewer, Boulder and MLO Dobsons in 2002 shown in Figure 1a, b, c indicate preliminary AIRS column retrievals approximately 7-12% higher than Dobson with a standard deviation of 5-7%. These preliminary comparisons showed no significant land/sea differences.

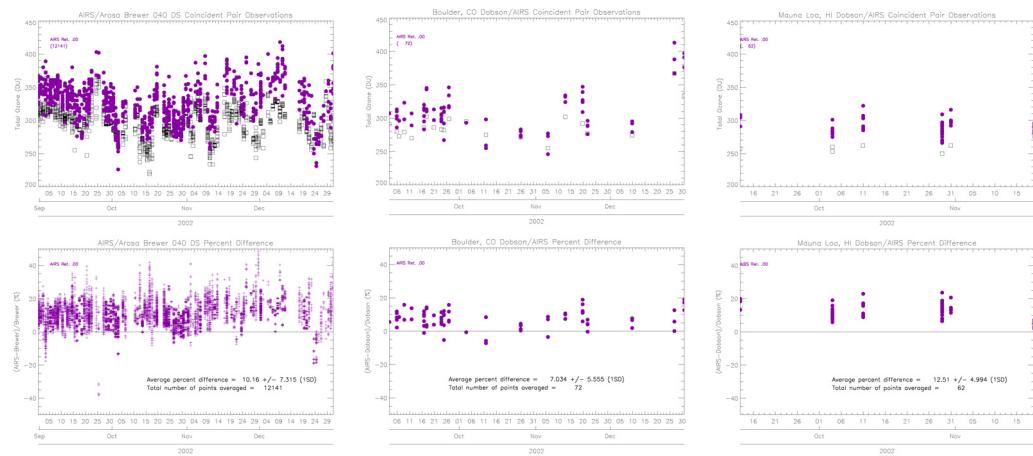


Figure 1: Coincident AIRS/Dobson total ozone columns in Dobson units in the top panels and as percentage of the ground-based measurement in the bottom panels for a) Arosa, b) Boulder, and c) Mauna Loa.

We have chosen to focus on the global ozone AIRS vs. TOMS comparison maps during January 2003 because this month comprises nearly all of the AIRS ozone data available at this time. All of the individual-day comparisons appear on our website, http://vortex.nsstc.uah.edu/atmchem/AIRS/first_year.html, un=AIRS, pw=ozone2003, and the January average appears here.

The January 2003 average global TCO from TOMS v8 and AIRS v3.1.9 are shown in Figure 2 (a) and (b) respectively. These TOMS data are the pre-public-release, aerosol-and-sea-glint-corrected most current TOMS level-2 product. They are believed by the TOMS Science Team to be the most accurate total ozone column estimates available to date. Although we show comparisons for all data available globally, we concentrate on water-pixel retrievals between 40 S and 40 N (Figure 2c). Within this region, the largest percent differences are located mostly in the southern hemisphere, specifically between 10-30 S, with peak differences around 15-16% off the southern coast of west Africa. These differences are not necessarily all attributable to AIRS errors. Equatorial regions of the eastern Pacific Ocean show the best agreement with differences of 0% +/- 4%. Figure 2 (d) shows the one-sigma standard deviation of the average percent difference for January 2003 to range between 1-7% in the tropics. The standard deviations show a broad longitudinal minimum at the equator and increase toward higher latitudes, both northward and southward. Northward of 30 N the standard deviations increase to as high as 10-11%. This larger variation could easily be attributed to a seasonal increase in tropopause dynamics at mid- and higher-latitudes which directly affects the size of the stratospheric ozone column and hence the TCO.

The zonal structure of the percent difference is shown in Figure 2 (e.) The overplotting of the cosine-weighted zonal average column percent differences for the 31 days of January 2003, with the average for the entire month overlaid in red, clearly shows a latitudinal dependence in the different TCO amounts observed by these two instruments. AIRS overestimates the TCO with respect to TOMS at all latitudes except between 45 S and 65 S.

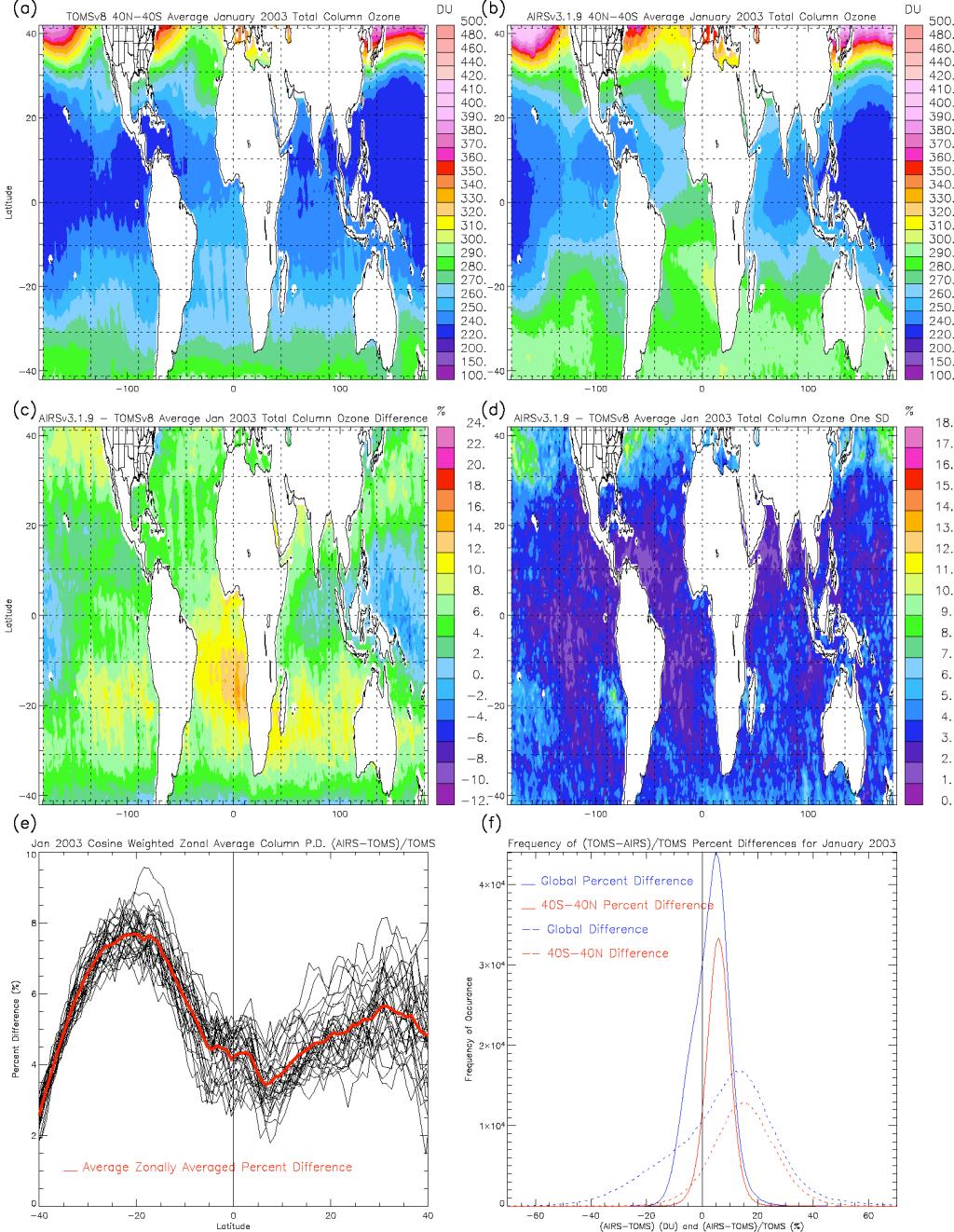


Figure 2. Results of TOMS version 8 and AIRS version 3.1.9 total ozone column observations averaged over January 2003. Panel (a) is the TOMS v8 ozone column measurement, (b) AIRS v.3.1.9 ozone column, (c) AIRS-TOMS % difference, (d) standard deviation of AIRS-TOMS differences, (e) cosine-weighted latitudinal distribution of AIRS-TOMS differences for all days in January and their average, (f) frequency distribution of AIRS-TOMS differences ± 40 degrees (red solid in %, dashed in Dobson Units) and ± 90 degrees in blue.

We also compared the January, 2003 v3.1.9 AIRS ozone column to the Level 3 gridded TOMS Version-7 data (which is not corrected for aerosol interference nor for sea-glint errors) and presented the results at the Fall 2003 AGU meeting. A combined land and ocean (AIRS-TOMS)/TOMS average difference of $(7.1 \pm 4.5)\%$ (1_s) was found between 40°S and 40°N . The ocean-only difference was slightly better at $(6.1 \pm 3.0)\%$. A positive correlation of the AIRS-TOMS difference with skin temperature was noted, possibly caused by “contamination” of the ozone retrieval by boundary-layer CO₂. This led to the testing of re-selected channels for ozone retrievals. Figure 3 presents O₃, CO₂ and H₂O line strengths, frequencies, and ground-state energies (E") for the 9.6 μm band (data from HITRAN96). Superimposed are available AIRS channel frequencies, with original (pre-v3.5.0) and modified ozone channels. This new channel selection better avoids weak, temperature-sensitive CO₂ lines near the end of the ozone P-branch at $\sim 1040\text{ cm}^{-1}$ and in the R-branch at $\sim 1060\text{ cm}^{-1}$.

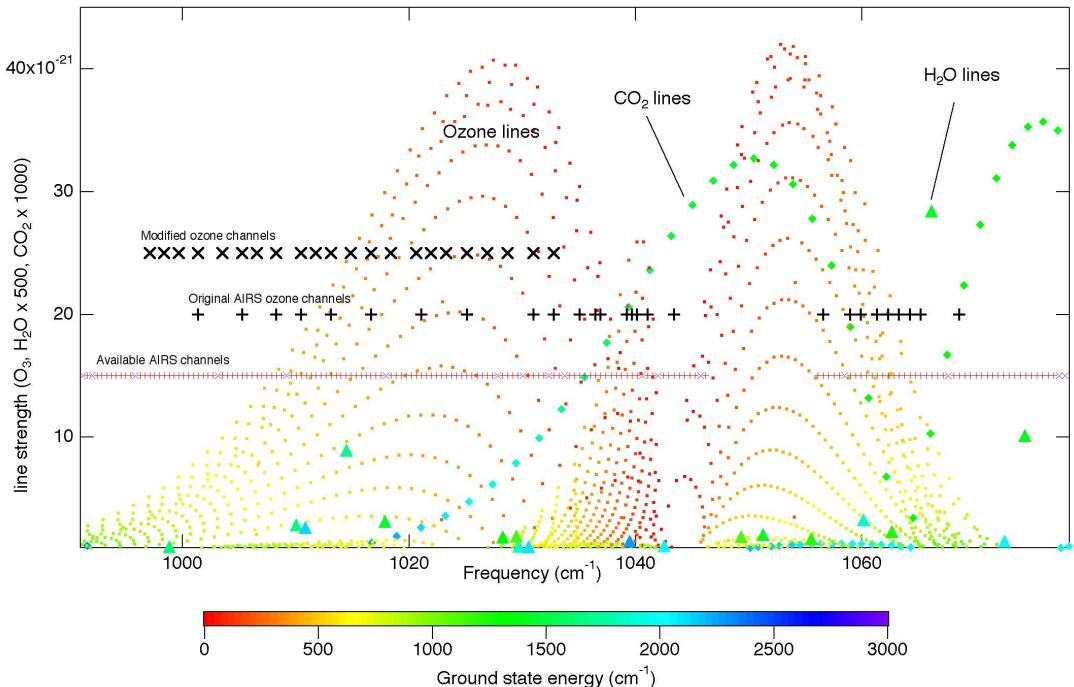


Figure 3. Line strengths of O₃ (dots), H₂O (triangles), CO₂ (diamonds) and AIRS channels vs. frequency. The color scale is ground-state energy. Available AIRS channels are marked by red +'s while bad channels are marked by blue x's.

We tested both the original and modified channel selection on the Sept. 6, 2002 “focus day.” Gridded TOMS data only partly covered the globe on that day, so the retrieval was on daytime granules between $\sim 60^{\circ}\text{W}$ to $\sim 170^{\circ}\text{E}$ (and between 40°S and 40°N). Table 1 and Figure 4 below compare current and modified channel results in land or ocean retrievals. The modified channels show significantly improved agreement with TOMS, over both land and ocean.

Table 1: Comparison of AIRS ozone retrievals to TOMS using original and modified ozone channels for the Sept. 6, 2002 focus day.

| (AIRS – TOMS) / TOMS (median difference %) (1s) | Original ozone channels | Modified ozone channels |
|--|-------------------------|-------------------------|
| All pixels | 5.3 ± 6.5 | 3.5 ± 6.8 |
| > 99% land | 8.7 ± 7.3 | 4.5 ± 7.9 |
| > 99% ocean | 3.7 ± 4.9 | 2.8 ± 5.7 |

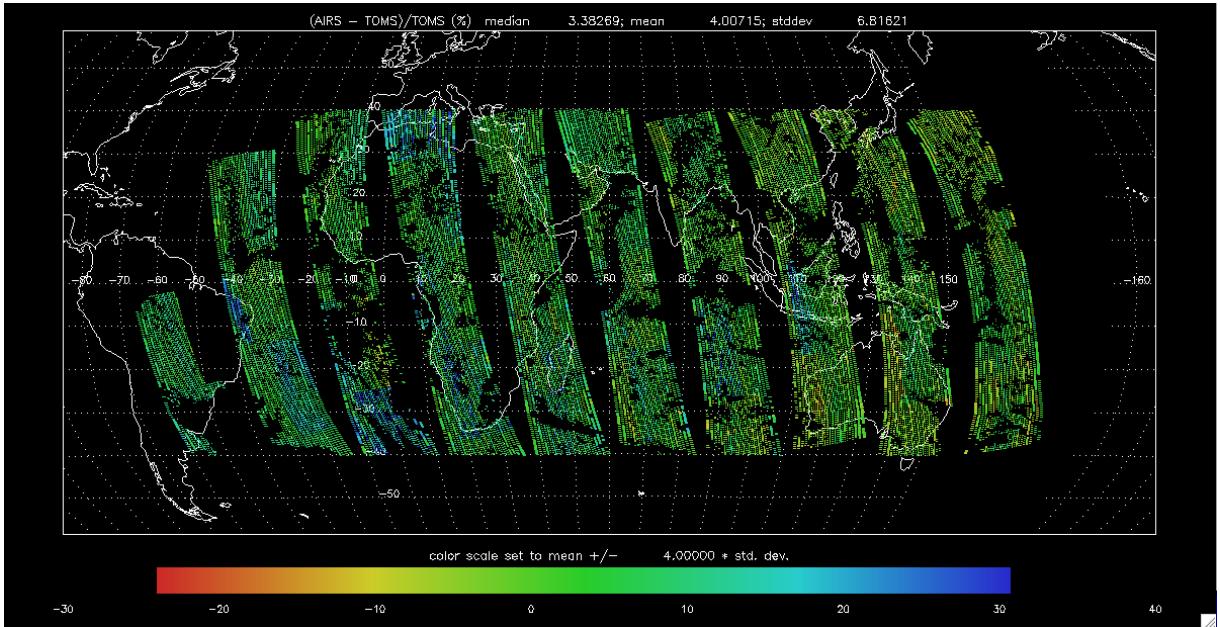


Figure 4. (AIRS – TOMS)/TOMS results using modified, P-branch only channels. Note that the color scale is limited to the mean $\pm 4\%$.

A linear relationship between the AIRS-TOMS difference and the skin temperature was previously observed. Figure 5 shows these regressions for the Sept. 6, 2002 data, while the Table 2 below categorizes them in land or ocean retrievals. Improvements, particularly for land retrievals, result from using the modified channels. (Indeed, over land the slope decreases by more than an order of magnitude to where it is not statistically significant.)

Table 2: Comparison of the slope of the AIRS/TOMS relative difference vs. skin temperature using original and modified ozone channels. The Sept. 6, 2002 focus day was used for this comparison.

| Slope of (AIRS-TOMS)/TOMS vs T_{skin} (%/K) (1_) | Current ozone channels | r | Modified ozone channels | r |
|--|------------------------|------|-------------------------|-------|
| All pixels | 0.225 ± 0.003 | 0.36 | 0.109 ± 0.004 | 0.16 |
| > 99% land | 0.078 ± 0.008 | 0.10 | 0.002 ± 0.008 | 0.002 |
| > 99% ocean | 0.204 ± 0.006 | 0.23 | 0.160 ± 0.008 | 0.16 |

A result of these analyses is that the modified ozone channels have recently been incorporated in the new AIRS v3.5.0 processing scheme. Level-2 data from some 12 “focus days” from September, 2002 through January, 2004 have been re-retrieved using v3.5.0 processing. For regions between 40°S and 40°N, the daily average (AIRS–TOMS)/TOMS difference ranges from 2.3 to 5.9%, with an average of $4.0 \pm 1.3\%$ (1_).

Our current efforts also include validation of the polar ozone, particularly during the polar night. The left panel of Figure 6 illustrates V3.5.0 AIRS retrieval of column ozone over Antarctica for September 6, 2002, while the right panel illustrates the relative difference with TOMS in the sunlit regions. (Note that TOMS only returned data for about half the globe on that day.) The median (AIRS–TOMS)/TOMS difference is $12.4 \pm 15.9\%$ (1_), larger than mid-latitudes, but still potentially useful for characterizing the morphology of an impending ozone hole.

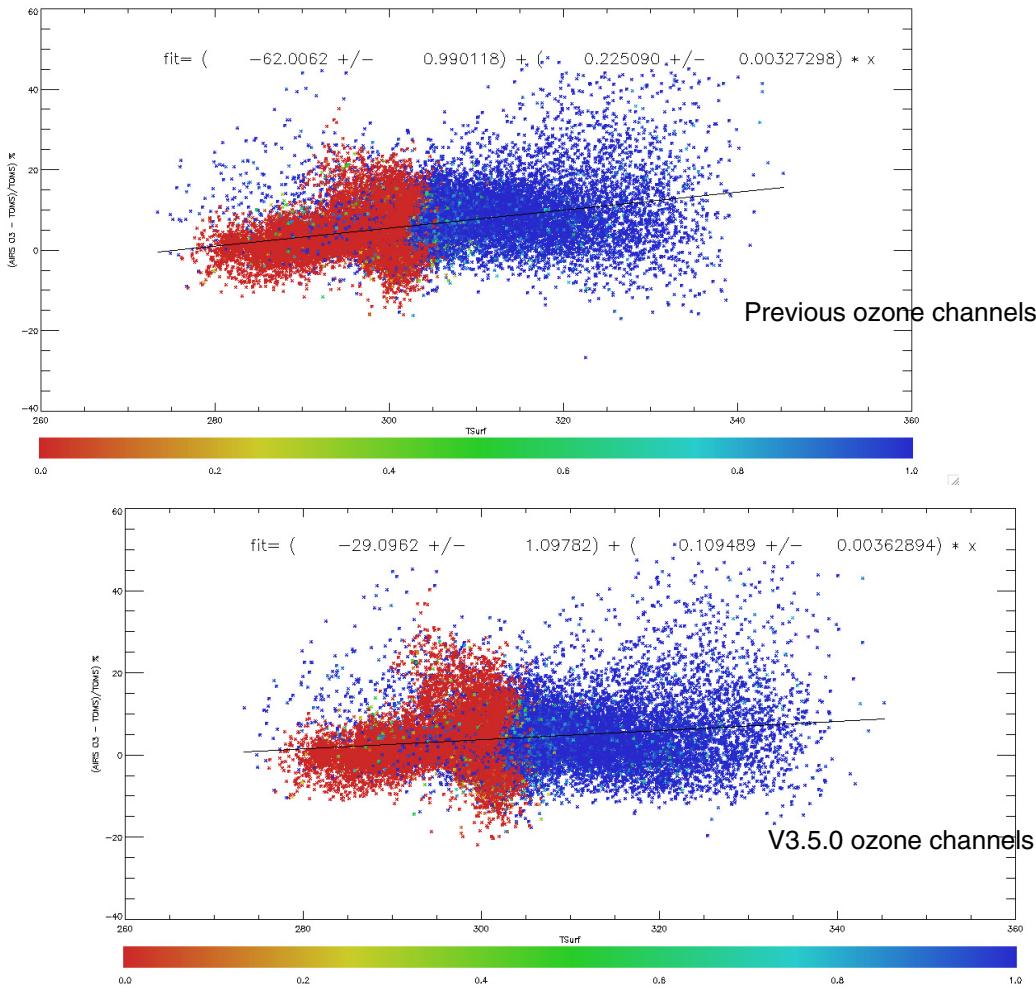


Figure 6. Relative AIRS-TOMS difference vs. skin temperature for 9/6/2002 between 40°S and 40°N. The upper panel illustrates this difference using the original channels for ozone, while the bottom panel shows this using the re-selected channels (see Figure 3.) The color scale is land fraction.

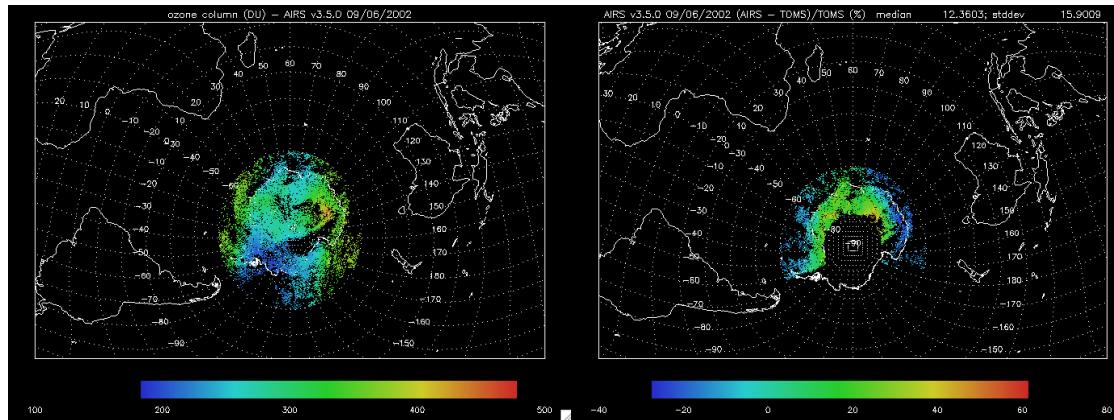


Figure 6. AIRS retrieved ozone column (in Dobson Units) for the South Pole region on 9/6/2002 (left panel) and relative difference with TOMS in sunlit regions (right panel.) Note that TOMS returned values for only half the globe on that day.

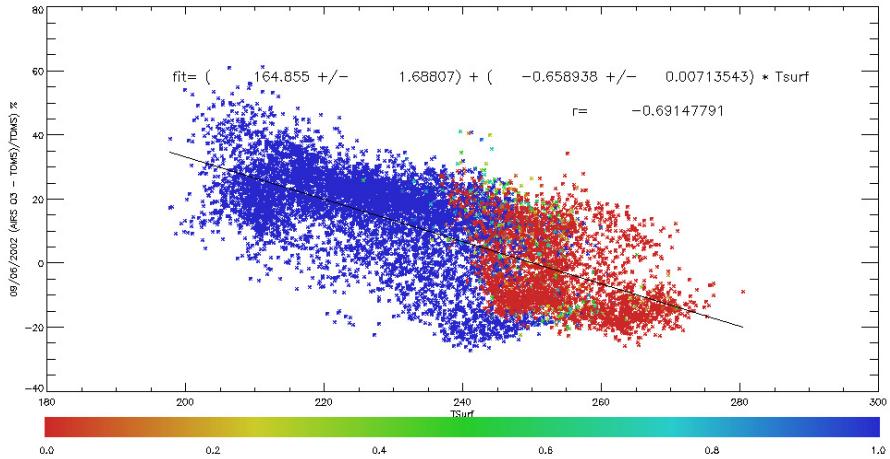


Figure 7. AIRS-TOMS difference vs. skin temperature.

Figure 7 illustrates the AIRS-TOMS difference as a function of skin temperature, with the highest difference over the coldest land regions. We note that AIRS retrievals of temperature have not been validated over polar regions, and as AIRS temperature retrievals over ice improve, we expect better agreement of the ozone retrievals with TOMS.

Conclusion

The AIRS ozone product with suggested retrieval algorithm improvements shows the potential for being a scientifically useful dataset of global total ozone column measurements. Additional investigation into the dependencies of AIRS retrievals on various parameters (e.g., skin temperature) will improve the veracity of these measurements. Unique scientific studies into the nighttime Polar Regions may be possible.

References

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